Are Cane Toads *Rhinella marina* impacting Ghost Bats *Macroderma gigas* in Northern Australia?

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ABSTRACT

Faunal studies in the Riversleigh/Boodjamulla area of north-western Queensland undertaken between 1990 and 2011 revealed a decline in the number of Ghost Bats *Macroderma gigas*. Cane Toads *Rhinella marina* reached Boodjamulla in 1986 and were widespread by 1988. The last reported sighting of a Ghost Bat in Boodjamulla was in 1993.

In view of the absence of sightings, an extensive targeted survey for Ghost Bats was initiated in 2012 in the Riversleigh World Heritage Area and elsewhere in the Boodjamulla National Park (NP). No Ghost Bats were found in historic roosting sites. Helicopter surveys located another 24 potential Ghost Bat sites but none contained evidence of occupation by these carnivorous bats. A number of cave features that were considered to be important to Ghost Bats and Cane Toads were recorded and samples of Ghost Bat droppings were collected from the cave floor. All of the historic roosting caves contained water and were inhabited by Cane Toads.

In 2013, the search for Ghost bats was extended to the Camooweal Caves NP, the nearest known Ghost Bat colony to Riversleigh/Boodjamulla. Ghost Bats were found in seven caves in the Camooweal Caves NP. Again, cave features were recorded and cave floor samples taken. Cane Toads were not present in any of the caves at Camooweal Caves NP despite being present in the local area.

In 2013/2014, Ghost Bat surveys were extended to Kakadu NP in the Northern Territory. Many historically occupied roost sites were found to be devoid of Ghost Bats, but some more remote caves still retained extant populations (albeit in low numbers). Cave floor samples of droppings revealed that toads were being taken as a very minor component of the vertebrate prey of Ghost Bats. One dead Ghost Bat was found with a partly masticated toad in its oesophagus. This, and other indirect evidence, indicates that Cane Toads are being taken by Ghost Bats on an occasional basis and that these episodic predation events may be a significant factor in the observed decline in Ghost Bats populations in areas where Cane Toads are abundant.

Key words: Ghost Bat *Macroderma gigas*, Cane Toad, *Rhinella marina*, declines, toxin susceptibility.

DOI: http://dx.doi.org/10.7882/AZ.2016.028

Introduction

The arrival and spread of the introduced Cane Toad *Rhinella marina* into Australia has had a significant impact on native wildlife. These impacts, often most noticeable during the first few years following the arrival of toads into an area, include the rapid loss of vertebrate predators (Shine 2010), especially frog-eating predators (Doody *et al.* 2009). Predator numbers in affected ecosystems can slowly recover from the initial impact of toads but rarely return to pre-toad impacted levels.

The main animals groups to be adversely impacted by toads in Australia have been the goannas (Family Varanidae), snakes (Family Elapidae) and predatory marsupials such as quolls (Family Dasyuridae) (Shine 2010). Other fauna groups that do not prey heavily on frogs or toads may decline at a much slower rate and their decline may not be detected by initial fauna surveys. To date, there have been no documented cases of native species becoming extinct as a result of the advent of Cane Toads in Australia, although there are examples of regional extinctions (e.g. White 2003).

The Ghost Bat *Macroderma gigas* is the only Australian bat that includes native frogs in its diet (Richards *et al.* 2008). Ghost Bats inhabit northern Australia in areas that are being colonised by Cane Toads. There have been no reported instances of interactions between Ghost Bats and Cane Toads and until 2013 (White and Madani 2014) there had been no reports suggesting that these bats may be preying on toads. Cane Toads arrived at Riversleigh

World Heritage Area and Boodjamulla National Park in north-western Queensland in 1986 and were widespread by 1988. At the time Ghost Bats were regularly sighted in Boodjamulla NP (C. O'Keefe: Pers. comm.). The last confirmed sighting of a Ghost Bat in either area was on the 19th of September 1993 (C. O'Keefe: Pers comm). In 2012, targeted surveys for Ghost Bats were carried out by A.W. in the Riversleigh / Boodjamulla NP in response to the apparent decline in Ghost Bat numbers in the region. These surveys failed to locate extant Ghost Bats and historic roosting sites were either abandoned or only contained the skeletal remains of dead bats. In each case, Cane Toads were found to be now residing in, or at the entrance to the roost caves. No other changes to the roosting sites were apparent. The apparent disappearance of Ghost Bats and the presence of Cane Toads in Ghost Bat roost sites suggest a causal link.

The present study aimed to find if there was evidence of a link between the arrival of Cane Toads and the decline of Ghost Bats.

Methods

The approach adopted was three-fold: firstly, to survey areas where Cane Toads and Ghost Bats had occurred in sympatry for a relatively brief period (c. 1-5 years) and to see if a decline could be detected; secondly, as Ghost Bats will often take prey items back to roost sites before devouring them, a search of the floor of the roost sites was undertaken to look for evidence of predation of toads, and finally, if recently dead Ghost Bats were found, an autopsy of these animals was carried out to determine recent prey items. Demonstrating a direct impact was likely to be difficult in view of the apparent long lag time between the advent of toads and the disappearance of Ghost Bats.

Survey Areas

All surveys were confined to northern Australia (Figure 1). The Riversleigh/Boodjamulla region includes the Riversleigh World Heritage Area (part of Boodjamulla NP). These large land units are located approximately 350 km north-west of Mt Isa in Queensland. Camooweal Caves NP is located 260 km west of Mt Isa in Queensland. Kakadu NP was the only area in the Northern Territory to be surveyed and lies about 270 km east of Darwin.

In all of the areas surveyed, records of Ghost Bat sites and numbers prior to the arrival of Cane Toads were scant. Consequently, the bat caves located and survey data recorded during this study may be used as baseline data for future bat surveys.

Riversleigh/Boodjamulla NP:

Only three cave roost sites were known for Ghost Bats in the Riversleigh/Boodjamulla region. These were Two Trees Cave, Forbes Inferno Cave and Kerb Meister Cave. Unfortunately there are no historic records of Ghost Bat numbers in these caves. As the region contains large expanses of exposed limestone, it was expected that other caves were likely to exist that could be used as roost sites by Ghost Bats. The region has few roads and finding new caves was only made possible through the use of helicopters. The opportunity to conduct helicopter surveys to locate new potential Ghost Bat sites became

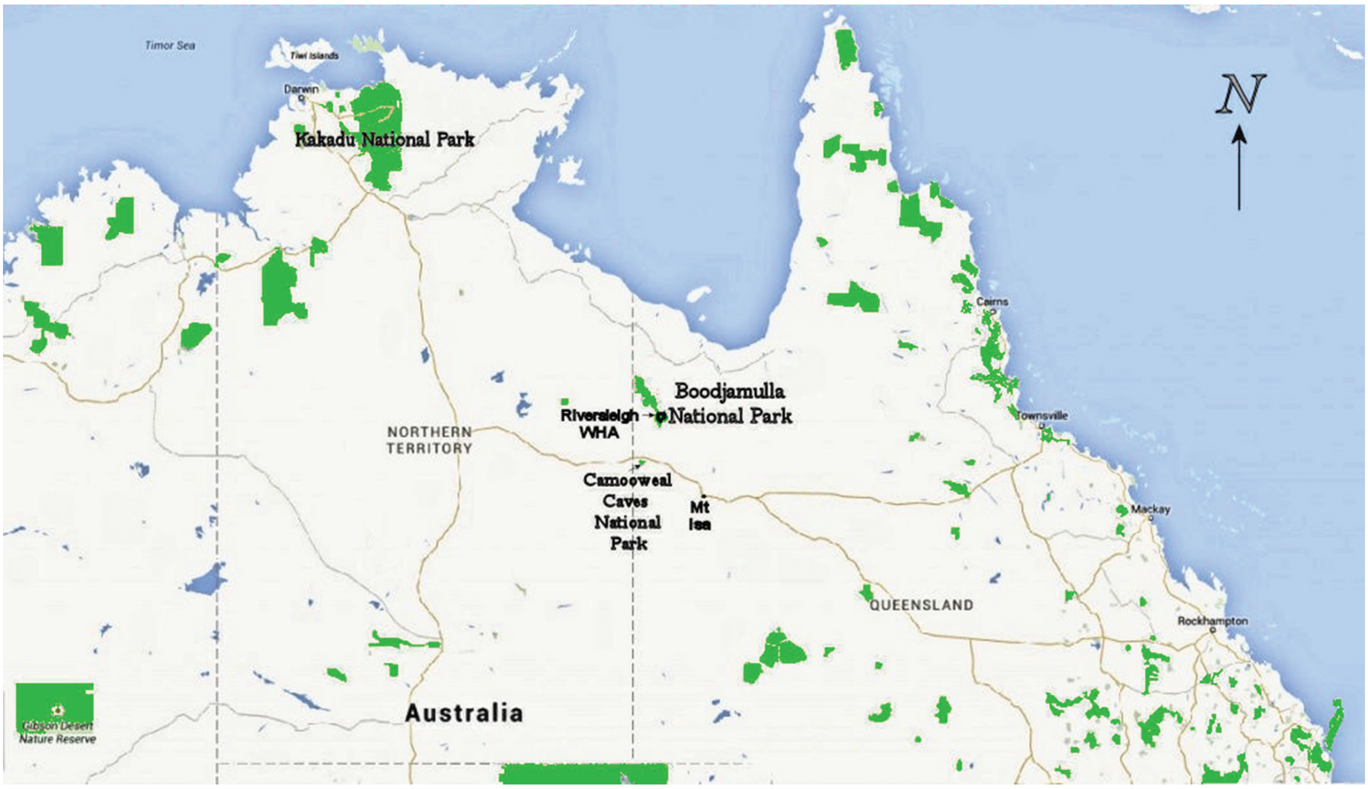

Figure 1: Location of Ghost Bat survey areas

available in June 2013, and over 12,000 ha of limestone terrain was searched, resulting in the discovery of an additional 24 potential roost caves.

Camooweal Caves NP:

The nearest known presumed extant roosting sites to the Riversleigh Ghost Bat caves are in the Camooweal Caves NP. In July 2013, the authors undertook a bat survey of some of these caves to determine if Ghost Bats were extant, to record bat numbers, to record cave conditions, to collect roost dross material for later analysis and to search for corpses of dead Ghost Bats. The region has over 40 known caves and eight of these caves were surveyed for Ghost Bats (Kalkadoon Cave, Great Nowranie Cave, Little Nowranie Cave, Four Mile East Cave, Canellan Cave, Danes Cave, Niggle Cave and Tar Drum Cave).

Kakadu NP:

Kakadu NP lies a further 800 kilometre north-west of Riversleigh. Cane Toads did not reach this area until 1995. Fourteen Ghost Bat sites were known in Kakadu NP but no recent bat surveys had been carried out. Thirteen caves were surveyed by the authors in January and August 2014 Again, cave conditions were recorded, cave floor samples taken, and bat corpses collected for autopsy.

Ghost Bat Survey

Visual counts of Ghost Bats were made during the daytime whilst bats were roosting. The roosting caves were approached and entered quietly. Survey personnel would remain hard pressed against cave walls and once in position would quickly sweep the cave roof with the low beam of a red light to estimate numbers of roosting bats. All efforts were taken to avoid startling the bats into flight. If the bats were startled or took to flight before the bat counts had been made, the surveyors would retreat from the cave, to return at a later date and reattempt the bat count. No bat trapping was undertaken.

Cave Conditions

Cave features were recorded in the roosting chamber of each Ghost Bat cave where possible. Features recorded included air temperature (°C), humidity, presence or absence of open water in the cave, distance to nearest open water outside the cave, presence of cane toads, presence of other bat species and recording evidence of cave disturbance (such as repeated human visitation, proximity of bush fires, vegetation cover across cave entrance and use of cave by other species).

Cave Floor Samples

Samples from the floor of eight caves were collected for analysis. Between 6 and 10 samples (of about 100g) of the dross were collected from different locations within each cave and stored in labelled plastic bags for transportation back to Sydney. The samples contained bat guano as well as animal remains that had presumably been left by Ghost Bats. The caves sampled were Two Trees (Figure 2) and Forbes Inferno (from Riversleigh/Boodjamulla), Four Mile East, Danellan and Kalkadoon Caves (Camooweal NP) and Ngarradji Warde Djobkeng (Figure 3), Blue Rocks 4 and Hawk Dreaming 2 (Kakadu NP).

In Sydney, the samples were transferred to an open sorting tray and the bony debris was extracted from the dross. The bones were then sorted into broad taxa, namely those derived from mammals, reptiles, birds and amphibians. The amphibian bones were further subdivided into those derived from toads and native frogs. The total number of bones of each type was then recorded.

Dissection of Recently Dead Ghost Bats

The carcasses of recently dead Ghost Bats were collected from two sites in Kakadu NP (Ngarradji Warde Djobkeng and Hawk Dreaming 2: Figure 4), sealed in plastic wrap and transported back to Sydney. The bats were later unwrapped and the stomach and throat was dissected and any vertebrate prey material removed and identified.

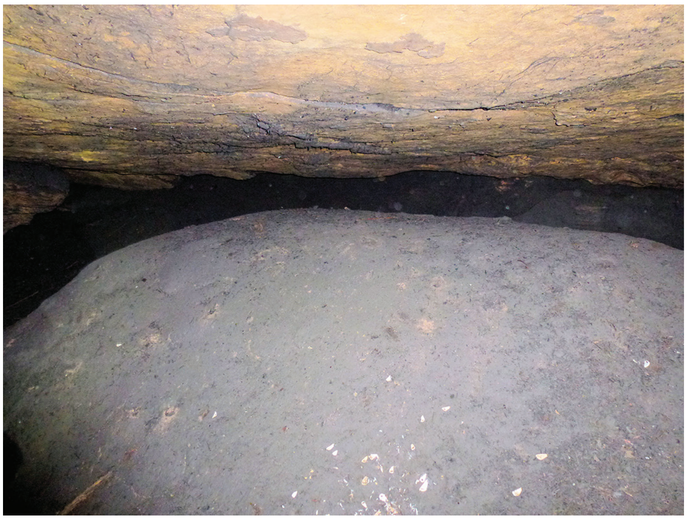

Figure 2: Large Ghost Bat guano mound Two Trees Cave Riversleigh World Heritage Area.

Figure 3: Entrance amphitheatre to the caves at Ngarradji Warde Djobkeng, Kakadu NP.

Results

Ghost Bat Surveys

Of the 24 potential Ghost Bat caves surveyed, live Ghost Bats or evidence of recent occupation was only found at eleven sites (Table 1). No live Ghost Bats were found at the sites in Riversleigh/Boodjamulla whereas live Ghost Bats were found at seven of the eight caves surveyed at Camooweal Caves NP. Ghost Bats were only found at four out of the fourteen sites surveyed in Kakadu NP. The surveys were not all carried out at the same time of year: the surveys at Riversleigh and Camooweal were carried out in July, whereas the Kakadu surveys were conducted in January and August.

Cave Characteristics

Occupied and unoccupied Ghost Bats caves had similar ambient conditions: they were typically warm (ie. air temperatures above 28°) and humid (always above 50%). (Table 2). Most occupied caves (11 out of 12) did not have toads present whereas most unoccupied caves had toads in them (8 out of 15).

Comparison of Sites with and without Ghost Bats.

Cave floor samples were analysed from eight caves; Two Trees and Forbes Inferno (Figure 5) (from Riversleigh/ Boodjamulla area) were abandoned Ghost Bat caves, whereas the other six caves were still in use by Ghost Bats.

Mammal, bird, reptiles and amphibian bones were collected from the majority of sites. Only the samples from Forbes Inferno cave lacked any amphibian remains, whereas in each of the other caves amphibian bones comprised between 2% and 11% of the vertebrate remains collected (Table 3). Birds were the most commonly found vertebrate taxa in the dross representing as much as 78% of the total bone samples in some roost sites (Blue Rocks 4 and Ngarradji Warde Djobkeng).

Dissection of dead Ghost Bats

A total of 11 Ghost Bat carcasses were collected for dissection. Of these, only two contained identifiable

Table 1. Surveyed caves occupied by Ghost Bats (2012-2014)

Area	Cave	No. Ghost Bats Counted	Other Bats species Present
Camooweal CavesNP	Four Mile East	33	*Hipposideros ater*
	Canellan	9	*Vespadelus finlaysoni*
	Danes	3	*Vespadelus finlaysoni*
	Great Nowranie	18+	*Hipposideros ater*
	Little Nowranie	7+	*Hipposideros ater*
	Kalkadoon	24	*Hipposideros ater*
	Niggle	28+	*Hipposideros ater*
Kakadu NP	Nawurlandja	1	*Taphozous georgianus*
	Blue Rocks 4	28	*Taphozous georgianus*
	Blue Rocks 7	5	*Taphozous georgianus*
	Hawk Dreaming 2	14	*Taphozous georgianus*

Note:The number of Ghost Bats counted at Great Nowranie, Little Nowranie and Niggle Caves are likely to be a minimum number as not all chambers of these caves could be surveyed.

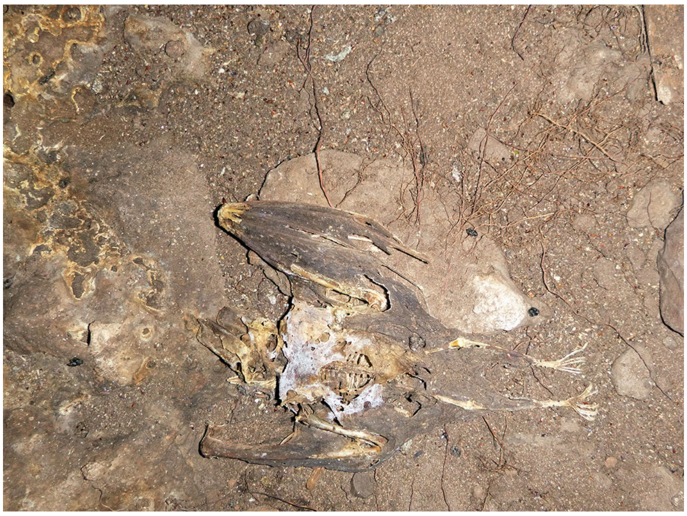

Figure 4: Dead Ghost Bat, Hawk Dreaming, Kakadu NP.

Figure 5: John Prince holding Ghost Bat jaw, Forbes Inferno Cave, Riversleigh World Heritage Area.

Table 2. Cave Characteristics of Occupied and Unoccupied Ghost Bat Caves.

Area	Cave	Date	Air Temp (0C)	Humidity (%)	Open Water in Cave (Yes/No)	Distance to Nearest Outside Water (m)	Cane Toads Present (Yes/No)
Riversleigh/ Boodjamulla	Two Trees	4.7.2013	29.5	85	Yes	>500	Yes
	Forbes Inferno	1.7.2013	31	95	Yes	>500	Yes
Camooweal	Four Mile East	7.7.2013	32	83	Yes	4500	No
	Canellan	10.7.2013	28.5	55	No	650	No
	Danes	10.7.2013	29.5	55	No	650	No
	Kalkadoon	7.7.2013	29	68	Yes	7300	No
	Great Nowranie	8.7.2013	29	58	Yes	600	No
	Little Nowranie	8.7.2013	31`	70	No	600	No
	Tar Drum	9.7.2013	29	60	No	2400	Yes
	Niggle	9.7.2013	29	65	Yes	1500	No
Kakadu	Ngarradji Warde Djobkeng	4.1.2014	33.5	60	Yes	>500	Yes
	Nawurlandja	6.1.2014	34.4	78	Yes	50	Yes
	Rockholes Mine	7.1.2014	28	64	Yes	1600	Yes
	Blue Rocks 1	11.8.2014	33.2	78	No	400	Yes
	Blue Rocks 2	11.8.2014	34.1	75	No	400	Yes
	Blue Rocks 3	11.8.2014	33.5	83	No	450	No
	Blue Rocks 4	11.8.2014	31.7	73	No	350	No
	Blue Rocks 5	11.8.2014	32.2	67	No	400	Yes
	Blue Rocks 6	11.8.2014	31.8	69	No	400	No
	Blue Rocks 7	11.8.2014	32.3	66	No	400	No
	Riflefish Dreaming	14.8.2014	33.6	78	No	300	Yes
	Hawk Dreaming 1	13.8.2014	32.5	74	No	850	No
	Hawk Dreaming 2	13.8.2014	30	68	No	1400	No
	Jabiru Dreaming	15.8.2014	30.2	74	No	80	No

Table 3. Vertebrate Remains in Cave Floor Dross
Analysis of Cave Floor Dross

Area	Cave	No. Samples Taken	No. Mammal Bones	No. Bird Bones	No. Reptile Bones	No. Toad Bones	No Frog Bones	Total No of Bones
Riversleigh/ Boodjamulla	Two Trees	6	57 (38%)	74 (50%)	3 (2%)	4 (3%)	11 (7%)	149
	Forbes Inferno	4	23 (41%)	33 (59%)	0 (0%)	0 (0%)	0 (0%)	56
Camooweal	Four Mile East	6	69 (36%)	85 (44%)	16 (8%)	0 (0%)	22 (11%)	192
	Canellan	4	43 (35%)	51 (41%)	19 (15%)	0 (0%)	10 (8%)	123
	Kalkadoon	6	33 (27%)	77 (64%)	3 (2%)	0 (%)	8 (7%)	121
Kakadu	Ngarradji Warde Djobkeng	6	22 (8%)	214 (78%)	13 (5%)	4 (1%)	22 (8%)	275
	Blue Rocks 4	4	18 (15%)	95 (78%)	6 (5%)	0 (0%)	3 (2%)	122
	Hawk Dreaming 2	4	14 (10%)	97 (71%)	11 (8%)	5 (4%)	10 (7%)	137

bone remains of prey items. Blue Rocks 2 (Kakadu NP) contained four limb bones that belonged to a fledgling bird (Bar-shouldered Dove). Hawk Dreaming 2 contained a partial skull, cervical vertebrae and shoulder girdle of a small adult cane toad (Figure 4).

Discussion

Evidence of Decline of Ghost Bats in Northern Australia

Ghost Bats have totally disappeared from Riversleigh/Boodjamulla. The last recorded and verified sighting was in 1993. Ghost Bats were not particularly common in this area and only three roosting caves were known (Two Trees, Forbes Inferno and Kerb Meister Caves). The first two caves have been visited a number of times and no live Ghost Bats have been seen or recorded in any of these caves since the 1990s. Kerb Meister Cave has not been revisited as the cave cannot be relocated.

In Kakadu NP, 14 known Ghost Bat sites were surveyed and only four continue to be used by the bats. One site (Ngarradji Warde Djobkeng Cave complex) was known to hold the largest colony of Ghost Bats in the park, with informal counts made in the 1990s of over 800 Ghost Bats at this site (I. Morris pers. comm). The site is now devoid of Ghost Bats and the state of decay of the guano suggests that Ghost Bats have not been in this area for at least 5 years. Bats are known to be seasonal in their movements and these Ghost Bat surveys were conducted in different months (January and August at Kakadu NP). It is possible that the number of live Ghost Bats encountered during these surveys would have been different at other times of the year, however the cave floor droppings provide an aseasonal measure of the use of the cave by Ghost Bats.

Of the four remaining colonies of Ghost Bats in Kakadu NP, two recorded less than 10 individuals (Nawurlandja, Blue Rocks 7). The fourth colony (Blue Rocks 4) numbered 28 animals. The apparent recent decline in the number of extant sites and bat numbers at these sites suggests that the status of Ghost Bats in Kakadu NP should be reassessed.

Cane Toads arrived in Kakadu NP in 1995 and within a year were widespread across the wetlands of the park. At Riversleigh/Boodjamulla, Cane Toads arrived in late 1985 and the last Ghost Bats were sighted eight years later. Kakadu NP had many more known and larger colonies of Ghost Bats than Riversleigh/Boodjamulla. Ghost Bats have co-existed in Kakadu NP with Cane Toads for almost 20 years, but it is not known if the remaining colonies are stable or whether they are in slow decline and heading to ultimate extirpation.

The extent or the uniformity of the decline in Ghost Bats across northern Australia is not known. There are areas where declines in bat numbers do not appear to have taken place (such as at Cooktown: Woinarski *et al.* 2012). In this study, Ghost Bats were detected in seven of the eight caves surveyed at Camooweal Caves NP, an area that has also been exposed to Cane Toads. It is not known if the Ghost Bat population at Camooweal Caves NP is stable or in decline.

Cane Toads have been present in parts of Queensland for up to 80+years. Ghost Bats have significantly declined during this period. There are six (confirmed) and possibly up to eleven genetically distinct populations of Ghost Bats in Queensland (Worthington *et al.* 1999). Of these, only one population (Cooktown-Kings Plain/Wallace Creek) appears to be secure . Three are presumed extinct (Riversleigh-Boodjamulla; Blackbraes/Chudleigh and the Wet Tropics (Mt Consider, Cardwell and Atherton). A further three have less than 30 animals remaining in them (Cape Hillsborough, Mt Etna and Mitchell/Palmer), although it is not known how large these populations were before the introduction of Cane Toads. The eastern Queensland populations have fared particularly poorly with six of the seven near-coastal populations being in severe decline or possibly extinct (Woinarski *et al.* 2012).

Ghost Bats have suffered previous declines in other areas of Australia, not related to the presence of Cane Toads. Ghost Bats disappeared from southern Australia in the 1960s (Churchill and Helman 1990) and now only occur in northern Australia.

Susceptibility of Ghost Bat Roosting Sites

Ten caves (Two Trees, Forbes Inferno, Tar Drum, Rockholes Mine, Blue Rocks 3 and 5, Riflefish Dreaming, Wild Hawk 1 and Jabiru Dreaming) were assessed that had recently lost their resident Ghost Bat populations (Table 2). No obvious differences could be found between these caves and those that still retained a population of Ghost Bats. In general, Ghost Bats roosting caves were warm (air temperatures 28° or more), humid (>50% humidity) chambers that were not exposed to direct light or wind. Nine of the 24 caves surveyed had water either in the caves or near the entrance, thirteen had open water within 500 m of the cave entrance (Table 2).

The only measured factor that appeared to correlate with the loss of Ghost Bats was the presence of Cane Toads: all twelve extinct roost sites surveyed now contained living toads. The presence of Cane Toads in these caves is likely to be related to the presence of water there but it is likely that toads also seek shelter in caves away from direct sunlight and heat.

The cave sites that still retained Ghost Bats were generally dry caves that were more than 750 m from an open water source. These dry caves were less likely to be used by Cane Toads as shelter sites.

Evidence of Predation of Cane Toads by Ghost Bats

The strongest evidence from this study for the predation of Cane Toads by Ghost Bats comes from the analysis of the bat droppings on the cave floor and from the dissection of dead bats. Toad bones were found in the dross from three caves (Two Trees, Ngarradji Warde Djobkeng and Hawk Dreaming 2; Table 3). The bones were all from small to medium-sized toads (Snout-vent lengths 2-5 cm) and were not shattered or broken implying that little mastication had taken place. Related (but not articulated) bones were also often found together.

Other toad bones were also found in the caves that appeared to be unrelated to the presence of Ghost Bats. The skeletons of several toads were found in situ and the skeletons showed no signs of predator attack. These skeletons were typically from larger toads and were most often found in the damper edges of the caves. They were not found near the Ghost Bat guano mounds. Cane Toads were observed to forage around the perimeter of the bat guano mounds in search of cockroaches and other invertebrates, but rarely ventured onto the dry, powdery surface of the old guano mounds (A. White pers. obs.).

The cave floor samples were all taken from central portions of the guano deposits and no bones from larger toads were present in these samples.

In 2014, a recently dead Ghost Bat (Figure 6) was collected from Hawk Dreaming 2. The bat had died but the left leg had remained locked onto a low rock ledge. When dissected, part of the cranium, cervical vertebrae and shoulder girdle of a small toad were found in the mouth and throat of the dead bat (Figure 7). Toad skin was still present on the bones and the bones did not show any signs of heaving been chewed. The toad appeared to have become wedged in the mouth of the bat and may not have been able to be disgorged by the bat. No other toad bones were found beneath the dead bat and location of the remainder of the toad skeleton was not determined.

Patterns of Ghost Bat Declines from Cane Toad Predation

The impact of toad predation by other Australian native predators has been well studied. In many cases precipitous declines in predator populations have occurred within only a few years of the arrival of Cane Toads into an area. Mayes *et al.* (2005) described the rapid decline of goanna and snake populations in response to toads; Oakwood (2004a, b; Watson and Woinarski 2003) similarly reported dramatic declines in the numbers of Northern Quolls D*asyurus hallucatus* in Kakadu NP and surrounding areas following the arrival of toads. These observations have been subsequently supported by other field studies (Doody *et al.* 2009; Griffiths 2007; Woinarski *et al.* 2001).

The preliminary risk assessment of Cane Toads in Kakadu NP stated that the predation of Cane Toads by native wildlife was the greatest risk to the biodiversity of the park (van Dam *et al.* 2002). The risk assessment did not include Ghost Bats as a potential casualty of the toad invasion.

The sudden decline of many native animals has been attributed to the naivety of native animals to toad toxins and the consequences of toad predation (Shine 2010). Indeed, it has been a feature of the impact of toads that die-offs occur rapidly and the declines are readily apparent. This is clearly not the case for Ghost Bats. If the decline and disappearance of Ghost Bats at Riversleigh/Boodjamulla is due to cane toad predation there was a seven year delay between the arrival of toads and the first suspicion that Ghost Bats were in decline. In Kakadu NP, toads arrived in 1995 but concerns about the plight of Ghost Bats have only now been raised, some 20 years later. The greater "lag" time for the Kakadu Ghost Bats to noticeably decline is presumably due to the much larger and more diverse colonies of Ghost Bats in Kakadu NP compared to the fewer and more isolated colonies that were known in Riversleigh-Boodjamulla.

Regardless of the size and number of initial Ghost Bat colonies, if Cane Toads are responsible for the decline of Ghost Bats the decline has been less abrupt than for other predators. The most likely reason for the slower decline is that Cane Toads are not a major part of the diet but are an occasional (perhaps even an unintentional) prey item only. Ghost Bats forage opportunistically and disperse widely (Richards *et al.* 2008) and may only encounter toads as food at particular times of the year, such as during the dry season when their more usual prey species are in low numbers or absent.

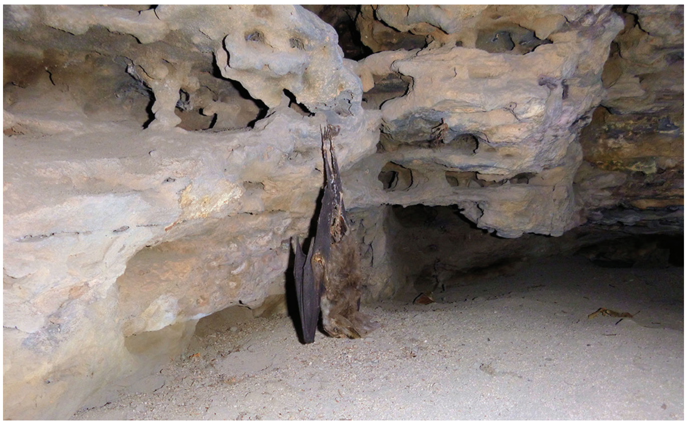

Figure 6: Dead Ghost Bat hanging from ledge, Hawk Dreaming 2, Kakadu NP.

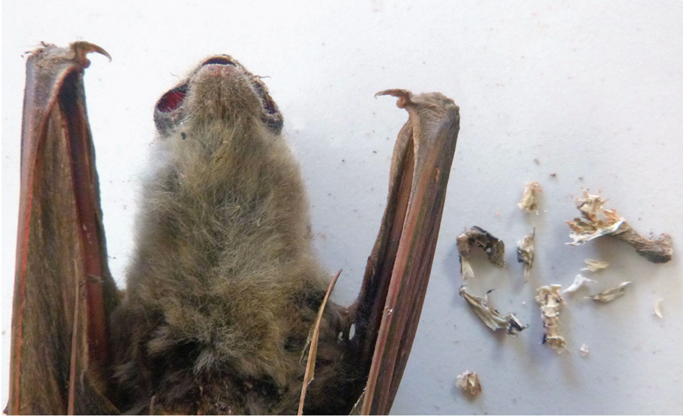

Figure 7: Remains of small cane toad removed from dead Ghost Bat collected at Hawk Dreaming 2, Kakadu NP.

Northern Australia is also suffering a drastic loss of small ground-dwelling mammals which comprise a significant part of the diet of Ghost Bats (Woinarski *et al.* 2014). The loss of which may be causing Ghost Bats to switch to alternate prey.

As toads were present in all of the now extinct Ghost Bat cave sites, it is also possible that those caves have attributes that favour the concentration of toads in that area, and hence increase their chances of being taken by Ghost Bats. All of these caves had open water present inside the cave or at the mouth of the cave and so they provided an ideal "dry season" retreat for cane toads. The retreat attributes of the cave for Cane Toads may be the reason for the slow decline of Ghost Bats in these caves.

In contrast, the caves at Camooweal Caves NP were not inhabited by toads because of their vertical entrances and lack of easy access to water. Toads do not congregate around these caves at any time, including the "dry season" (C. Saltmere pers. comm.). This implies that Ghost Bats would encounter toads less often and certainly not whenever they are exiting or returning to their roosting caves. At Camooweal Caves NP, Ghost Bats in Great Nowranie and Little Nowranie Caves have to travel 600 m to reach open water and areas where toads are resident; at Four Mile Cave and Kalkadoon Cave these distances increase to 4.5 and 7.3 km, respectively (Table 2).

Why are Ghost Bats susceptible to toad toxin?

Ghost Bats belong to the family Megadermatidae, a family that is centred about South-east Asia (Hall *et al.* 2002). Of the six bat species in that family only the Ghost Bats appear to be impacted by toad toxins. The remaining five species all occur in areas where other bufonids are present, yet there are no reports of bat declines. Either the South-east Asian megadermatids have learned to avoid toads as a prey item, or they are immune to toad toxin. The Australian Ghost Bats appear to not actively search out Cane Toads as prey but do not entirely avoid them. As the megadermatids are believed to have originated in south-east Asia (Corbet and Hill 1992) the susceptibility of Ghost Bats to toad toxin implies a loss of immunity, if immunity existed in the original founder population assuming that Cane Toad toxin is the same as that for South-east Asian Bufonids.

The Future of the Remaining Ghost Bat Colonies in Northern Australia

Ghost Bat declines are apparent throughout northern Queensland and probably also in the Northern Territory in areas where Cane Toads are established. At sites where Ghost Bats are still extant, such as Camooweal Caves NP, it is not known if these populations are stable or are in a very slow decline. Further monitoring of these colonies is required to resolve these questions.

For declining Ghost Bat colonies and colonies that have reached low numbers, such as in Kakadu NP, the fate of these colonies is uncertain. It is possible that these reduced colonies have survived until the present day because they are far enough removed from areas where toads are locally abundant and easy prey. It is also possible that they are in slow decline and will ultimately die out. Again, monitoring of these (and other) Ghost Bat colonies is critical to determine their prospects of long-term survival.

Cane Toads have recently entered Western Australia and new Ghost Bat populations will be exposed to the impacts of the toads. If cave attributes are a major factor in determining toad predation rates, there is a research opportunity to test this notion by modifying cave features before the arrival of toads. The decline and possible loss of Ghost Bats makes it imperative that proactive and experimental conservation initiatives are undertaken if the species is to be protected.

Acknowledgements

This project would not have been possible if not for the extensive assistance given by many people. The National Geographic Society provided the funds for the use of helicopters to conduct cave surveys in the Riversleigh/Boodjamulla area. Riversleigh research staff and volunteers assisted with site maps and information about cave access. Queensland National Parks and Wildlife Service assisted with the provision of permits and fauna records. John Prince, a ranger at Boodjamulla NP, kindly assisted with cave exploration and interaction with the Waanyi people of the area. Blake Dixon assisted with the abseiling and other speleological equipment. The Australian Speleological Federation provided advice and maps of caves in the Camooweal area. Colin Saltmere of Myuma Pty Ltd and the Dugalunji Aboriginal Corporation assisted with permits and access to Camooweal caves. In Kakadu Dr. Anne O'Dea was particularly helpful in getting permits, arranging meetings with the indigenous representatives and with providing past survey data. Natasha Nadji acted as our guide and advisor in sacred and sensitive areas in Kakadu NP.

This project was carried out under Scientific Permit WITK 13052513 for Queensland and permit number 826 for Kakadu NP.

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